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THE EFFECT OF SWITCH-HANDLE SHAPE UPON THE TIME REQUIRED FOR OPERATION

A Thesis
Submitted to the Faculty
of
Purdue University
by
Richard Henry Doolittle
In Partial Fulfillment of the
Requirements for the Degree
of
Master of Science
in
Industrial Engineering
June, 1950

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ABSTRACT

This investigation was undertaken to determine whether some one of several common shapes of handle for a generally-used type of switch would provide for a minimum of time required to operate the switch.

The time required by fifteen male operators to rotate a set of four switches to four different angles using five shapes of switch handles was measured.

The overall average times obtained (in hundredths of seconds) are as follows:

	30°	60°	90°	120°
Handle 1	189.6	225.9	259.0	300.3
Handle 2	174.8	222.8	240.3	261.3
Handle 3	199.2	233.3	278.0	317.1
Handle 4	187.4	221.0	251.7	296.8
Handle 5	186.8	236.5	275.5	315.0

An examination of the data shows that the round shapes of handles provided for the higher operating times while the generally rectangular shapes provided for the lower operating times.

THE EFFECT OF SWITCH-HANDLE SHAPE
UPON THE TIME REQUIRED FOR OPERATION

INTRODUCTION AND PURPOSE

A review of the literature shows that some consideration has been given to designing switch-handle shapes for appearance and indication of function[1]. Inquiries made at some of the leading electrical apparatus manufacturers, such as General Electric Company, Westinghouse Electric Corporation and Arma Corporation, reveal that industry has investigated the design of switch-handle shapes for appearance, feel to the hand and, in some cases, to provide better leverage for operation.

Apparently little consideration has been given to designing the shape with the thought in mind of providing for minimum operating time[2], as may be desired in the case of control panels for communication or radar equipment, computing machines and the like. Thus, this investigation was undertaken to determine whether some one of several common shapes of handle for a generally-used type of switch would provide for a minimum of time required to operate the switch.

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1. Price, Wesley, "Why Pilots Make Mistakes", Saturday Evening Post, April 19, 1947, p. 16.

2. Haines, Arnold, and Rosenbloom, J. H., "Ideal Torques for Handwheels and Knobs", Machine Design, August, 1946, pp. 145-148.

APPARATUS

The equipment used to measure the time required by the several operators consisted of the following: a plywood panel on which were mounted four ten-position rotary switches (Figs. 1 and 2), a relay and a normally-closed microswitch; a table upon which the panel, timing clock and power supply rested; a chair for the operator; a direct-current power supply for the timing clock and the relay; an electric clock which could be read to 1/100th of a second; and the required wiring.

The chair, an unpadded, wooden, straight-backed piece of furniture, was placed so that its centerline coincided with a line midway between the four switches and at a distance from the panel dependent upon the forearm measurement of the operator. The panel was adjusted vertically so that the elbow of the operator, when seated and when the upper arm was vertical and held against the side with the forearm at right angles to it, was ten inches below the center line of the switches. The dimensions and layout of the equipment are given in Figures 1, 2 and 3.

The switches used were commercially-obtained, ten-position wafer switches with spring ball detents. The average maximum torque required to rotate the switches from one detent to the next was three inch-pounds. The switch handles were also commercially-obtained. For the shapes and dimensions of these handles see Figures 4 and 5.

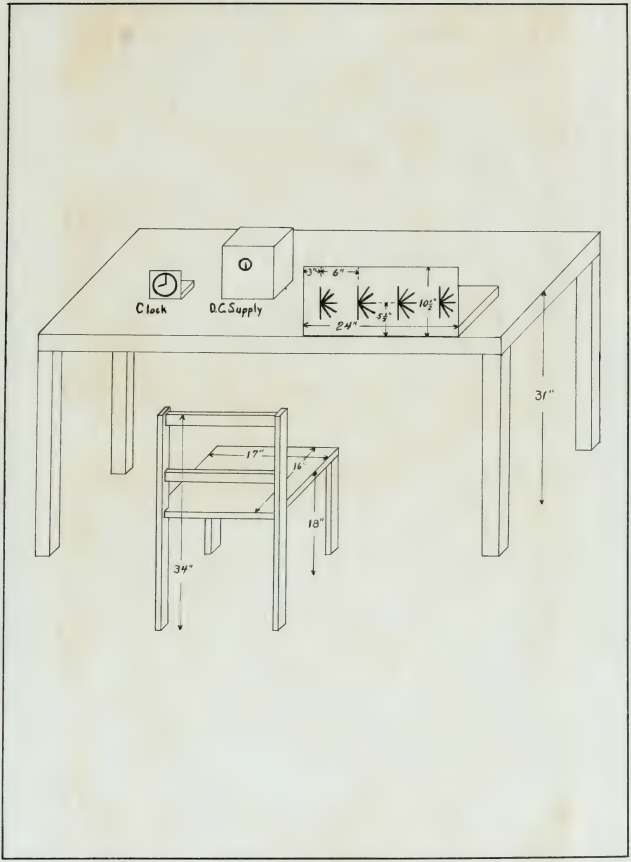

Fig. 1

Layout of equipment

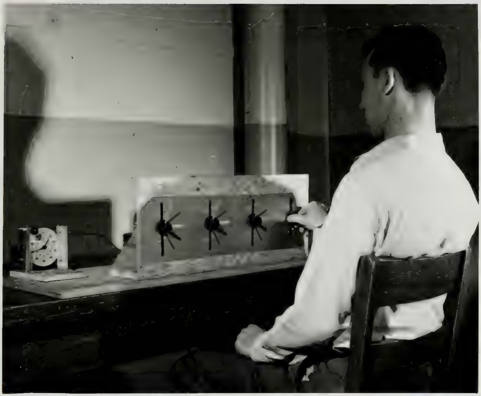

Fig. 2 View of equipment in operation

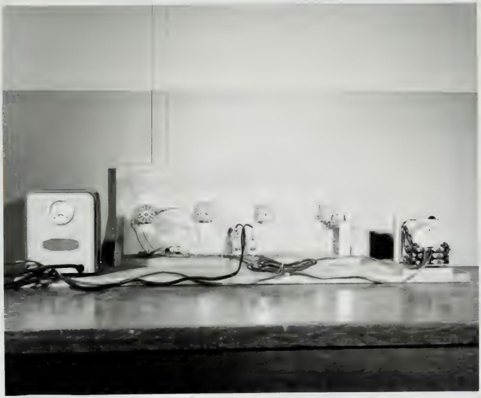

Fig. 3 Rear view of equipment

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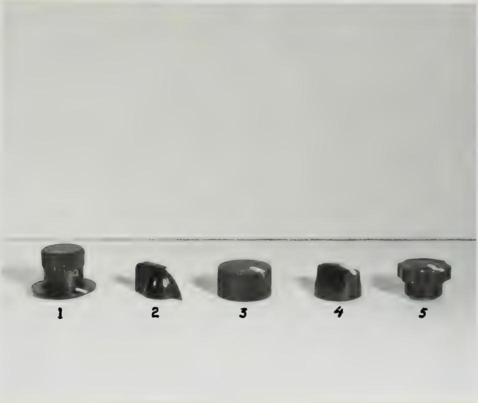

Fig. 4 Switch handles

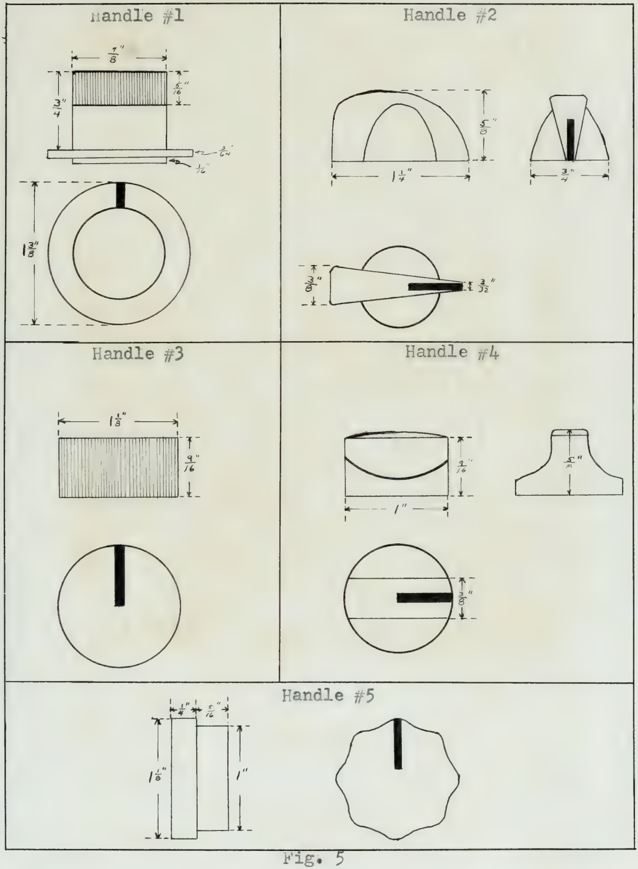

Fig. 5

Dimensions of switch handles.

The plane of rotation of the switches was vertical and the switches were rotated in the clockwise direction only. The test was limited to clockwise rotation in order to eliminate the effect of opposite directions of rotation. The angular positions of the switches were marked on the panel by quarter-inch wide colored stripes: black for the 0 degrees or vertical position; light blue for the 30 degree position; bright red for the 60 degree position; yellow for the 90 degree position; light green for the 120 degree position; gold for the 150 degree position; and black for the 180 degree position. Each switch handle was marked with a one-sixteenth inch wide white stripe (Figs. 4 and 5) which served as an index. The background around the switch handles and stripes was aluminum.

The microswitch was so positioned to a cam on the shaft of the left-hand switch that, as soon as the switch started to move, the circuit to the timing clock was closed and the clock began to run. The right-hand switch was wired to a relay so that the circuit to the clock was broken when the switch reached its designated position. This connection was changed for each required set-up so that the clock would stop when the required position was reached. The wiring diagram is illustrated in Figure 6.

The clock used was of the type in which the motor runs continuously while the movement of the hands is controlled by a solenoid-operated brake on a friction drive. Thus, the effect of inertia in the driving mechanism of the

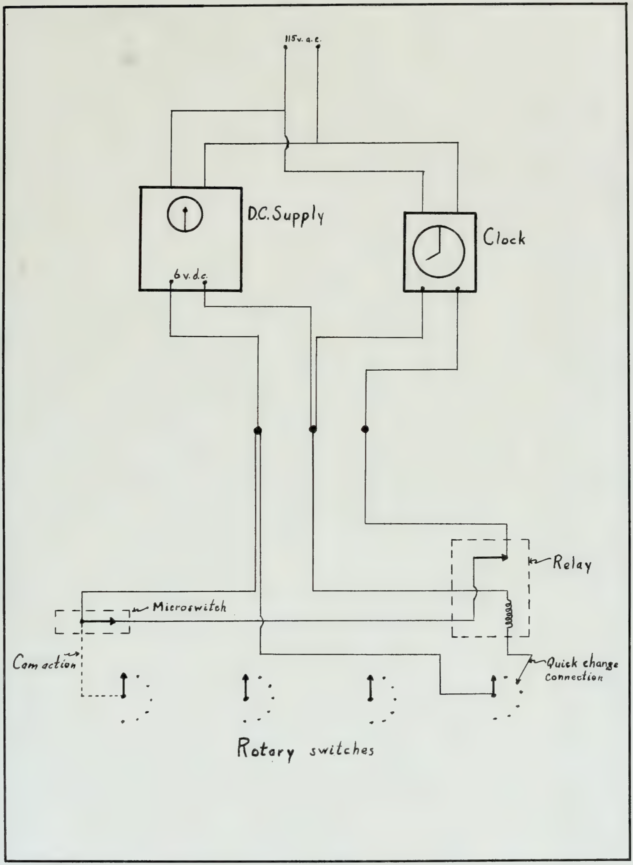

Fig. 6

Block wiring diagram

hands is minimized.

The power supply was a battery charger which required an input of 115 volts a.c. and which had an output of 6.5 volts d.c. The clock motor required 115 volts a.c. while the solenoid-operated brake and the relay required 6 volts d.c.

PROCEDURE

In order to facilitate the application of the experimental results to actual equipment, an attempt was made to present the test problem in a manner which would resemble an application in actual use. Since a great many switchboard and control equipment operators are seated at their jobs, and since it was desired that the effects of physical differences be minimized[3], the test operators were seated.

Before beginning the test, each operator was asked to fill out an operator data sheet. This data sheet, shown in Appendix C, Figure 8, was used to insure that all operators were free of abnormalities which might affect the results and to aid in tracing down any inconsistencies in operator performance which might develop.

When the sheet had been filled out, the operator was asked to be seated in the test chair. He was then asked to hold his upper arm vertical and against his side with his forearm extended at right angles to it. The chair was moved so that the tips of the operator's fingers just touched the edge of the table. The height of the panel was adjusted by means of blocks so that the elbow of the operator, with his arm in the position just described, was ten inches below the centerline of the switches.

[3] For a discussion of physical differences, see Tufts College Institute for Applied Psychology, Handbook of Human Engineering Data, parts I and II, Medford, Mass., 1949.

The operator was then asked to identify the colored stripes as the colors were named, in order to eliminate any operators who might be color blind. After this check, the operator was asked to position each switch in the red (60 degree) position, starting with the left-hand switch and using only his right hand. The left hand was not used so that all operators would have the same motion pattern and to eliminate the effects of two-handed operation. In order to eliminate the possibility of becoming familiar with one shape of handle, each switch was provided with a differently-shaped handle for the test run.[4]

The regular runs were then commenced and were presented in a previously-designed random order as shown in Appendix C, Figure 9. The position of the operator at the beginning of each run was erect in the chair with his hands in his lap. The following set of instructions was read to the operator: "The position to which the switches are to be rotated will be designated by color. You will use only your right hand and rotate the switches only in the clockwise direction. You will start with the left-hand switch and operate the switches from left to right. You are to position each switch accurately in the designated position as rapidly as possible. Accuracy is of prime importance, but you should work as rapidly as you think you can without making errors."

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[4] For a discussion of the psychological aspects of this procedure, see Chapanis, A.R., Garner, W.R., and Morgan, C.T., Applied Experimental Psychology, New York, John Wiley & Sons, Inc., 1949.

The desired position of the switches was designated by color and the operator was given the oral order, "Begin". He then raised his right hand from his lap and advanced it to the left-hand switch. The switches were operated from left to right and in a clockwise direction of rotation. At the completion of the run on each handle, the operator was asked to relax in the chair while the next handle to be presented was installed on the panel.

Each operator was required to make three complete runs and the average of the times was computed to be used for analysis purposes. Each of the three runs was identical. That is, the operator was presented with the complete sequence of five handles and four angles (as shown on the sample data sheet in Appendix C, Figure 9) three successive times.

RESULTS

The overall average times obtained from this investigation are shown in Table 1 below. The individual operator's average times are shown in Table 2. The actual time values obtained for all operators for all handles are given in Appendix A, Tables 3, 4 and 5.

	30°	60°	90°	120°
Handle 1	189.6	225.9	259.0	300.3
Handle 2	174.8	222.8	240.3	2[illegible]1.3
Handle 3	198.2	233.3	276.0	317.1
Handle 4	187.4	221.0	251.7	296.5
Handle 5	186.6	236.5	275.5	315.0

Table 1.

Overall average times.
(In hundredths of a second.)

An examination of Table 1 shows that handle #2 required the least time for all angles of rotation except 60°. Handle #4 required the least time for 60° and the second lowest time for 90° and 120°. Handle #3 required the most time for all angles except 60° where it required next to the highest time.

Curves based upon the data contained in Table 1 are shown in Figure 7. The curves were fitted by the method of least squares and the equations are given in Appendix B. Examination of the curves shows that, for all angles of

Handle #1

Oper. No.	30°	60°	90°	120°
1	233	240	261	326
2	223	223	234	269
3	172	213	236	311
4	207	233	249	312
5	183	280	290	309
6	173	253	242	288
7	203	252	290	335
8	164	209	247	247
9	209	234	295	363
10	146	189	203	264
11	215	267	299	342
12	172	205	238	279
13	151	187	228	217
14	188	226	235	270
15	206	217	322	362

Handle #2

Oper. No.	30°	60°	90°	120°
1	194	233	252	284
2	184	240	286	295
3	162	199	221	311
4	185	228	275	301
5	176	274	281	291
6	152	197	202	225
7	205	261	222	281
8	167	215	227	317
9	187	231	229	306
10	135	195	195	230
11	204	250	279	318
12	137	176	208	271
13	147	172	191	209
14	172	222	207	282
15	191	230	270	288

Table 2.

Average time values for all runs.

(In hundredths of a second)

Oper. No.	Handle #3 30°	60°	90°	120°	Oper. No.	Handle #4 30°	60°	90°	120°
1	262	301	347	370	1	212	241	255	327
2	216	252	305	306	2	239	219	262	290
3	196	215	251	306	3	164	201	211	267
4	224	236	336	373	4	180	218	240	351
5	254	252	325	309	5	171	234	247	307
6	192	207	268	314	6	174	230	232	267
7	203	258	286	326	7	200	247	291	358
8	153	227	276	374	8	161	197	232	295
9	174	223	253	336	9	221	250	261	318
10	153	190	210	283	10	159	180	226	250
11	213	315	297	351	11	212	262	323	325
12	167	197	254	290	12	171	194	239	274
13	181	172	209	223	13	149	180	210	219
14	202	222	245	292	14	177	218	242	279
15	197	233	271	304	15	211	247	303	320

Table 2.

(Continued)

Handle #5

Oper. No.	30°	60°	90°	120°
1	220	302	304	398
2	218	243	285	280
3	178	213	286	276
4	210	231	266	355
5	205	253	288	356
6	177	236	256	285
7	212	289	352	397
8	165	204	253	311
9	173	269	254	305
10	151	179	220	273
11	208	288	334	349
12	164	214	267	302
13	147	171	235	209
14	169	218	245	306
15	202	235	286	326

Table 2.

(Continued)

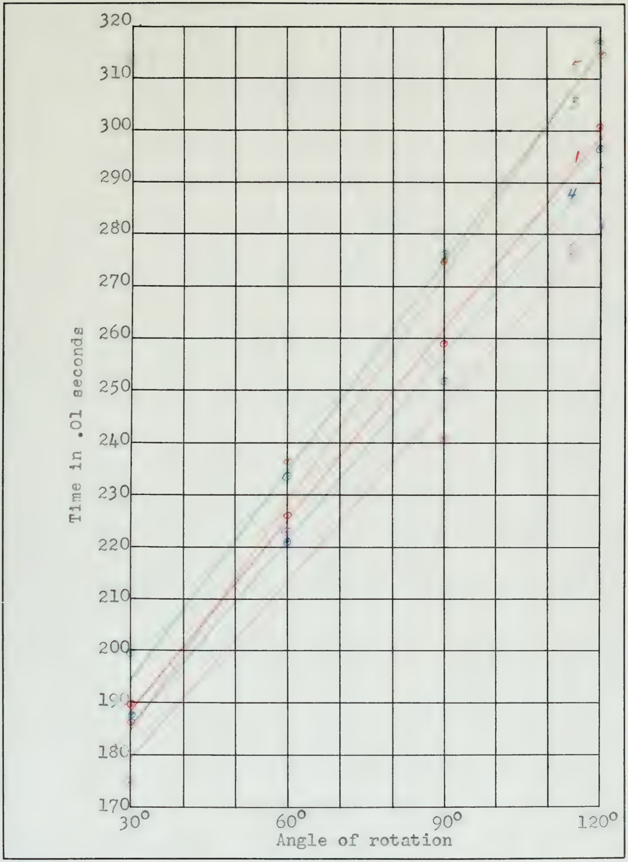

Fig. 7

Operating times vs. angles of rotation for switch handles (best-fitting curves)

rotation, handle #2 required the least time and handle #4 required the second lowest time. The other three handles required the highest times.

A statistical analysis of the data (see Appendix B, Table 10) obtained for each of the individual angles of rotation showed significant variances among operators and among handles. The variance among operators was consistently much higher than that among handles, which was to be expected due to individual differences in people.

For the complete data (see Appendix B, Table 11), the variances among handles and the variances among operators, for all angles of rotation, were highly significant. The overall variance among angles of rotation was highly significant although the interaction among handles and angles of rotation was significant only above the 5% level. The interaction among operators and handles and the interaction among operators and angles of rotation were both significant. The significances mentioned above are all at the 1% level unless otherwise stated.

CONCLUSIONS

The analysis of the data indicates that there is an optimum shape of handle for minimum operating time for switches under the conditions prevalent in this investigation. An examination of the plotted data leads to the belief that, in those situations requiring turning a switch handle to a specific point, the round shaped handle provides for the highest operating times while the generally rectangular shape provides for the lowest times. It is probable that those shapes more nearly resembling a pointer provide a better indication of position than the round shape with only an index mark.

APPENDIX A.

TIMES REQUIRED BY EACH OPERATOR
TO PERFORM THE SWITCHING OPERATIONS

Handle #1					Handle #2				
Oper. No.	30°	60°	90°	120°	Oper. No.	30°	60°	90°	120°
1	270	283	307	421	1	225	270	311	319
2	174	220	211	278	2	205	243	361	313
3	179	206	230	284	3	166	202	239	261
4	206	244	253	347	4	104	251	353	366
5	189	252	274	292	5	178	234	293	348
6	180	261	308	306	6	169	203	208	241
7	205	230	305	325	7	209	239	286	283
8	169	204	250	228	8	160	235	242	323
9	251	300	385	443	9	174	233	215	340
10	164	211	227	279	10	155	169	190	194
11	216	256	312	323	11	222	263	307	347
12	214	195	231	299	12	163	167	216	274
13	152	208	211	209	13	140	162	205	202
14	191	234	258	302	14	180	239	211	302
15	211	224	372	336	15	193	230	263	334

Table 3.

Time values for first run.

(In hundredths of a second)

Handle #3				
Oper. No.	30°	60°	90°	120°
1	280	346	335	413
2	164	235	336	284
3	222	233	236	271
4	294	247	441	437
5	198	312	300	335
6	183	276	387	280
7	203	270	293	344
8	152	248	238	397
9	192	222	247	327
10	159	214	228	314
11	209	312	306	363
12	156	215	290	288
13	234	190	233	272
14	243	214	215	265
15	200	225	278	332

Handle #4				
Oper. No.	30°	60°	90°	120°
1	240	289	305	388
2	204	211	248	257
3	177	195	220	261
4	184	231	259	341
5	183	262	290	352
6	208	321	267	312
7	204	256	283	379
8	150	179	252	201
9	236	278	257	382
10	169	175	232	279
11	232	259	348	380
12	158	195	241	286
13	154	159	226	229
14	192	218	250	273
15	204	220	344	355

Table 3.

(Continued)

Handle #5

Oper. No.	30°	60°	90°	120°
1	231	308	361	436
2	244	227	309	260
3	206	222	295	269
4	193	267	274	339
5	180	253	300	356
6	189	263	312	338
7	208	313	367	433
8	159	194	278	275
9	191	255	229	275
10	159	203	237	264
11	219	288	362	374
12	171	211	264	283
13	141	170	211	210
14	169	227	292	375
15	200	238	296	353

Table 3.

(Continued)

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	Handle #1					Handle #2			
Oper. No.	30°	60°	90°	120°	Oper. No.	30°	60°	90°	120°
1	236	236	249	284	1	188	210	233	260
2	193	218	248	269	2	184	276	226	321
3	172	214	241	364	3	164	199	221	343
4	227	239	262	310	4	180	220	240	303
5	184	316	263	302	5	191	292	324	265
6	172	213	230	300	6	147	194	200	205
7	190	216	290	317	7	205	311	260	301
8	147	198	219	213	8	178	222	220	303
9	178	197	230	286	9	198	225	242	292
10	143	171	212	280	10	156	219	231	286
11	218	275	289	374	11	202	244	278	239
12	149	228	269	295	12	124	174	220	270
13	157	177	231	227	13	183	187	197	215
14	197	229	261	275	14	170	224	206	290
15	212	213	326	497	15	160	252	278	271

Table 4.

Time values for second run.

(In hundredths of a second)

Handle #3					Handle #4				
Oper. No.	30°	60°	90°	120°	Oper. No.	30°	60°	90°	120°
1	279	263	335	359	1	204	201	223	350
2	305	287	316	326	2	307	228	231	290
3	184	204	241	261	3	161	199	202	257
4	185	221	266	353	4	169	203	214	321
5	383	224	293	323	5	162	225	224	313
6	214	169	209	288	6	166	225	224	268
7	217	260	280	307	7	205	219	224	359
8	151	237	289	355	8	151	198	222	274
9	167	224	273	399	9	195	220	204	282
10	161	168	215	292	10	167	192	212	243
11	195	272	284	341	11	205	269	323	319
12	165	196	245	261	12	158	225	234	254
13	157	159	204	200	13	147	162	180	210
14	176	223	260	321	14	176	207	259	311
15	192	247	296	265	15	220	234	284	294

Table 4.

(Continued)

Handle #5

Oper. No.	30°	60°	90°	120°
1	211	286	278	368
2	198	263	303	307
3	172	200	307	274
4	259	210	272	325
5	191	235	310	401
6	176	249	228	259
7	213	294	354	335
8	149	214	240	264
9	166	261	259	335
10	164	184	221	268
11	204	304	352	368
12	174	240	257	319
13	150	174	232	220
14	164	214	226	279
15	215	264	312	365

Table 4.

(Continued)

	Handle #1					Handle #2			
Oper. No.	30°	60°	90°	120°	Oper. No.	30°	60°	90°	120°
1	190	197	227	274	1	168	230	211	274
2	305	231	244	261	2	162	226	272	251
3	165	219	237	265	3	175	197	203	330
4	188	217	232	279	4	169	212	225	238
5	177	271	332	332	5	159	245	226	261
6	167	225	189	256	6	140	191	195	230
7	213	251	275	371	7	194	232	279	229
8	176	226	271	302	8	167	189	219	324
9	170	205	271	359	9	194	232	229	237
10	130	185	170	234	10	155	176	164	210
11	210	271	295	330	11	188	253	252	319
12	152	192	213	244	12	124	172	186	269
13	143	176	236	216	13	137	158	172	204
14	175	214	245	257	14	167	202	223	234
15	196	213	267	252	15	201	207	230	239

Table 5.

Time values for third run.

(In hundredths of a second)

Handle #3

Oper. No.	30°	60°	90°	120°
1	227	291	372	339
2	180	235	262	309
3	182	208	273	385
4	194	239	307	329
5	180	221	390	269
6	179	178	227	374
7	190	244	285	328
8	156	198	300	371
9	173	222	245	281
10	140	188	186	242
11	240	361	302	349
12	180	180	228	301
13	153	167	189	198
14	181	230	261	290
15	200	227	238	316

Handle #4

Oper. No.	30°	60°	90°	120°
1	192	232	237	242
2	205	218	246	322
3	163	209	212	282
4	196	215	246	370
5	166	214	[illegible]	257
6	155	203	204	221
7	191	265	301	337
8	151	215	216	329
9	232	252	261	311
10	140	173	225	242
11	231	259	303	295
12	197	161	221	253
13	145	159	187	218
14	163	233	216	253
15	209	237	[illegible]	312

Table 5.

(Continued)

Handle #5

Oper. No.	30°	60°	90°	120°
1	219	313	280	389
2	211	240	242	272
3	157	217	253	286
4	169	215	252	400
5	245	272	285	310
6	166	205	128	227
7	214	259	336	424
8	186	204	240	394
9	162	290	244	299
10	129	150	203	288
11	200	273	297	306
12	146	190	271	323
13	151	170	212	197
14	175	213	217	263
15	191	202	249	280

Table 5.

(Continued)

APPENDIX B.

CALCULATIONS USED IN THE EVALUATION OF THE DATA

For the purpose of analysis, the data in Table 2 were separated for each angle of rotation. The data in each group were simplified for computation by subtracting the same amount from each value in the group and arranged as shown in tables 6, 7, 8 and 9.

Each column was then totaled and the individual column totals labeled X_1, X_2, X_3, X_4, and X_5. The grand total of all data in the table was labeled Z. Each value in the table was squared and the sum of the squares labeled T^2. Each row was totaled and the individual row totals labeled Y_1, Y_2, Y_3, and so on up to Y_{15}.

The total variation, Q, was computed by means of the formula $Q = T^2 - \frac{Z^2}{km}$, where k is the number of columns and m is the number of rows.

The variation among column means, Q_c, was computed by means of the formula $Q_c = \frac{1}{m}(X_1^2 + X_2^2 + X_3^2 + X_4^2 + X_5^2) - \frac{Z^2}{km}$.

The variation among row means, Q_r, was computed by means of the formula $Q_r = \frac{1}{k}(Y_1^2 + Y_2^2 + Y_3^2 \ . \ . \ . \ + Y_{15}^2) - \frac{Z^2}{km}$.

The residual variation, Q_e, was computed by means of the formula $Q_e = Q - Q_c - Q_r$.

The column to column variance, σ_c^2, was computed by means of the formula $\sigma_c^2 = Q_c \div (k-1)$. The row to row variance, σ_r^2, was computed by means of the formula $\sigma_r^2 = Q_r \div (m-1)$. The residual variance, σ_e^2, was computed by means of the formula $\sigma_e^2 = Q_e \div (k-1)(m-1)$.

The F values for the variances between rows and between columns were computed by dividing the variances, respectively, by the residual variance. These F values were then compared with the $F_{.05}$ and $F_{.01}$ values from a table of F distribution for the proper degrees of freedom[5].

In like manner the variation, variance, and F values for total variation among handles, total variation among operators, total variation among angles of rotation, interaction between handles and angles of rotation, interaction between operators and handles, and interaction between operators and angles of rotation were computed and compared with the F-distribution table. All computed values are given in Tables 10 and 11.

The average times required by all operators for each handle and for each angle of rotation were computed. Equations for lines of best fit to the data were computed by the method of least squares and were plotted as shown in Figure 7. The computed equations are:

Handle #1 $y = 16.252 + 1.218\,x$

Handle #2 $y = 9.505 + 1.130\,x$

Handle #3 $y = 24.320 + 1.343\,x$

Handle #4 $y = 15.417 + 1.196\,x$

Handle #5 $y = 15.053 + 1.494\,x$

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[5] Snedecor, G.W., Statistical Methods Applied to Experiments in Agriculture and Biology, Ames, Iowa, Collegiate Press, 1934.

Oper. No.	Handle 1	2	3	4	5	ΣY	ΣY^2
1	96	57	125	75	83	436	40604
2	86	47	79	102	81	395	32811
3	35	31	59	27	41	193	8077
4	70	48	87	43	73	321	21951
5	46	39	117	34	68	304	23106
6	36	15	55	37	40	183	7515
7	66	66	66	63	75	336	22662
8	27	30	16	24	28	125	3245
9	72	50	37	84	36	279	17405
10	9	18	16	22	14	79	1341
11	78	67	78	85	71	379	28923
12	35	0	30	34	27	126	4010
13	14	10	44	12	10	90	2476
14	51	35	65	40	32	223	10675
15	69	54	60	74	65	322	20978
ΣX	790	567	934	756	744	3791	
ΣX^2	51366	27279	72612	48818	45704		245779

Table 6.

Computation data for 30° rotation.

	Handle						
Oper. No.	1	2	3	4	5	ΣY	ΣY^2
1	80	73	141	81	142	517	58335
2	63	88	92	59	83	385	30547
3	53	39	55	41	53	241	11845
4	73	68	76	56	71	344	23906
5	120	114	92	74	93	493	49985
6	73	37	47	90	78	325	23091
7	72	101	98	87	129	487	49199
8	49	55	67	37	44	252	13220
9	74	71	63	90	169	467	51147
10	29	35	30	20	19	133	3727
11	107	100	55	102	128	492	51262
12	45	18	37	34	54	188	7790
13	27	12	12	0	75	126	6642
14	66	62	62	58	58	306	18772
15	57	70	73	87	75	362	26672
ΣX	988	943	1000	916	1271	5118	
ΣX^2	75946	72287	80492	68366	131049		428140

Table 7.

Computation data for 60° rotation.

Oper. No.	Handle 1	2	3	4	5	ΣY	ΣY^2
1	70	94	156	64	115	499	55393
2	43	95	114	71	94	417	37747
3	45	30	60	20	95	250	15950
4	58	84	147	49	75	413	40055
5	99	90	137	56	97	479	49215
6	51	11	77	41	65	245	14557
7	99	91	95	100	161	546	63028
8	56	36	85	41	62	280	17182
9	104	38	64	70	63	339	25225
10	12	4	19	35	29	99	2587
11	108	88	106	134	143	579	69049
12	47	17	63	48	76	251	14547
13	35	0	18	19	44	116	3846
14	64	16	54	51	54	239	12785
15	131	79	80	112	95	497	51371
ΣX	1022	773	1275	911	1268	5249	
ΣX^2	84792	59605	132791	70327	125022		472537

Table 8.

Computation data for 90° rotation.

Oper. No.	Handle 1	2	3	4	5	EY	EY^2
1	117	75	161	118	189	660	94880
2	60	86	97	81	71	395	32007
3	102	102	97	58	67	426	38070
4	103	92	164	142	146	647	87449
5	100	82	100	98	147	527	57937
6	79	16	105	58	76	334	26662
7	129	82	117	149	188	665	94599
8	38	108	165	86	102	499	58133
9	154	97	127	109	94	581	69971
10	55	21	74	46	64	260	15154
11	133	109	142	116	140	640	82790
12	70	62	81	65	93	371	28179
13	8	0	14	10	0	32	360
14	69	73	83	70	97	392	31288
15	153	79	95	111	117	555	64685
EX	1370	1084	1622	1317	1591	6984	
EX^2	150192	94402	198014	135577	203979		782164

Table 9.

Computation data for 120° rotation.

	30° rotation		60° rotation
T^2	245779.000	T^2	426140.000
Σ^2	14371681.000	Σ^2	26193924.000
$\frac{\Sigma^2}{kn}$	191622.413	$\frac{\Sigma^2}{kn}$	349252.320
$\Sigma(\mathrm{KX})^2$	2943017.000	$\Sigma(\mathrm{KX})^2$	5319890.000
$\Sigma(\mathrm{RY})^2$	1145949.000	$\Sigma(\mathrm{RY})^2$	1995020.000
Q	54156.587	Q	76887.680
Q_c	4578.720	Q_c	5407.010
Q_r	37567.387	Q_r	49751.680
Q_e	12010.480	Q_e	21728.990
σ_e^2	214.473	σ_e^2	388.017
σ_c^2	1144.680	σ_c^2	1351.752
σ_r^2	2683.384	σ_r^2	3553.691
F_c	5.337	F_c	3.484
F_r	12.511	F_r	9.158

F_c			F_r		
$F_{.05}$	2.533	D.F.₁ = 4	$F_{.05}$	1.876	D.F.₁ = 14
$F_{.01}$	3.674	D.F.₂ = 56	$F_{.01}$	2.424	D.F.₂ - 56

Table 10.

Computed values for individual angles of rotation.

90° rotation		120° rotation	
T^2	472537.000	T^2	782164.000
T^2	27552001.000	T^2	48776256.000
$\frac{T^2}{kn}$	367360.010	$\frac{T^2}{kn}$	650350.080
$\Sigma(\Sigma X)^2$	5705333.000	$\Sigma(\Sigma X)^2$	9948610.000
$\Sigma(\Sigma Y)^2$	2162491.000	$\Sigma(\Sigma Y)^2$	3687336.000
Q	105176.990	Q	131813.920
Q_c	12998.860	Q_c	12890.580
Q_r	65138.190	Q_r	87117.120
Q_e	27039.940	Q_e	31806.220
σ_e^2	482.856	σ_e^2	567.968
σ_c^2	3249.715	σ_c^2	3222.645
σ_r^2	4652.728	σ_r^2	6222.651
F_c	6.730	F_c	5.674
F_r	9.636	F_r	10.956

F_c

$F_{.05}$ 2.536 $D.F._1 = 4$

$F_{.01}$ 3.674 $D.F._2 = 56$

F_r

$F_{.05}$ 1.876 $D.F._1 = 14$

$F_{.01}$ 2.424 $D.F._2 = 56$

Table 10.

(Continued)

Q(total)	436672.787		
Q(handles)	27219.887	σ_h^2	6804.972
Q(angles)	68637.613	σ_a^2	22879.204
Q(operators)	207362.187	σ_o^2	14811.585
Q(handles vs. angles)	8655.287	σ_{ha}^2	721.274
Q(handles vs. operators)	33235.213	σ_{ho}^2	593.486
Q(angles vs. operators)	32212.187	σ_{ao}^2	766.957
Q(residual)	59350.413	σ_e^2	353.276

F_h	19.262	($F_{.05}$	2.43	D.F.₁ = 4
		($F_{.01}$	3.44	D.F.₂ = 42
F_a	64.763	($F_{.05}$	2.67	D.F.₁ = 3
		($F_{.01}$	3.91	D.F.₂ = 56
F_{ha}	2.042	($F_{.05}$	1.92	D.F.₁ = 12
		($F_{.01}$	2.30	D.F.₂ = 14
F_{ho}	1.680	($F_{.05}$	1.42	D.F.₁ = 56
		($F_{.01}$	1.60	D.F.₂ = 3
F_o	41.926	($F_{.05}$	1.76	D.F.₁ = 14
		($F_{.01}$	2.20	D.F.₂ = 12
F_{ao}	2.171	($F_{.05}$	1.47	D.F.₁ = 42
		($F_{.01}$	1.72	D.F.₂ = 4

Table 11.

Computed values for complete data.

APPENDIX C.

SAMPLE DATA SHEETS

SAMPLE OPERATOR DATA SHEET

Operator No.____________ Weight____________

Date____________________ Height____________

Date of Birth___________ Wear glasses?______

Color Blind?____________ Visual defects?_____

Nature of visual defects_______________________________

____

Any broken bones or physical defects of arms or hands?_____

What bones broken?_____________________________________

What physical defects?_________________________________

How much experience at operating this type of switch?______

____

How do you feel? Unusually good_____ Good_____ Average____

Poor_____ Tired_____

How did you spend the last hour?

Class____ Taking a test____ Studying____ Working____ Eating__

Relaxing____ Other_____________________________________

____

AFTER TAKING TEST

To what extent were you prompted to work rapidly?

Greatly_____ Indifferently_____ Poorly_____

Distance of chair from table___________________________

Ambient illumination: Bright_____ Average_____ Dim_____

Figure 6.

Oper. #1

Hand.	Angle 30°	60°	90°	120°
1				
2				
3				
4				
5				

Oper. #2

Hand.	Angle 30°	90°	60°	120°
2				
3				
4				
5				
1				

Oper. #3

Hand.	Angle 30°	90°	120°	60°
3				
4				
5				
1				
2				

Hand.	Angle 120°	60°	30°	90°
4				
3				
2				
5				
1				

Oper. #5

Hand.	Angle 60°	120°	30°	90°
5				
2				
3				
1				
4				

Oper. #6

Hand.	Angle 60°	90°	120°	30°
4				
5				
1				
2				
3				

Figure 9.

Sample data sheet.

Oper. #7

Hand.	Angle			
	90°	60°	30°	120°
5				
1				
4				
3				
2				

Oper. #8

Hand.	Angle			
	30°	120°	90°	60°
5				
4				
3				
2				
1				

Oper. #9

Hand.	Angle			
	120°	30°	60°	90°
1				
4				
2				
3				
5				

Oper. #10

Hand.	Angle			
	60°	30°	120°	90°
3				
1				
5				
4				
2				

Oper. #11

Hand.	Angle			
	90°	120°	30°	60°
1				
5				
2				
3				
4				

Oper. #12

Hand.	Angle			
	120°	90°	60°	30°
2				
1				
5				
4				
3				

Figure 9.

(Continued)

Oper. #13

Hand.	Angle			
	90°	30°	120°	60°
3				
5				
1				
2				
4				

Oper. #14

Hand.	Angle			
	60°	120°	90°	30°
2				
3				
4				
1				
5				

Oper. #15

Hand.	Angle			
	90°	30°	60°	120°
4				
2				
1				
5				
3				

Figure 9.

(Continued)

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